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A Review on Biodegradation of Plastics

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ABSTRACT

Plastics are defined as the synthetic long chain polymeric units (Scott, 1999). They are non-metallic mouldable compounds, a property responsible for their widespread utility. They have become irreplaceable and an integral part of every sector of economy due to their easy availability, durability and stability. Owing to their better chemical and physical properties like lightness, strength and resistance to water, they have replaced paper and other cellulose based compounds for packaging and other utilities. Plastics derived from renewable sources are called bio plastics. It is an alternative to plastics. Plastics are main cause of environmental pollution. When compared to other traditional methods of disposal of plastics biodegradation is pollution friendly.

KEYWORDS: *Plastics, biodegradation, polymer, cellulose and microorganisms*

I. INTRODUCTION

A polymer is a macromolecule composed of repeating structural units connected by covalent bonds. The repeating structural units are called monomers which join to form the polymers. Plastics are organic polymers of high molecular mass. The name plastic is derived from its property of plasticity. Plasticity is the property of any material by which the material is able to irreversibly deform without breaking. The term plastic is derived from the Greek word "plastikos" which means "capable of being shaped or molded".

Organic and inorganic raw materials such as carbon, silicon, hydrogen, nitrogen, oxygen and chloride are used for the manufacture of plastic and that are in use today. Most common forms of plastics are polyethylene, poly-propylene, polystyrene etc. Plastics are seen as environmental threat because they are difficult to degrade. Plastics have displaced traditional materials like wood, stone, horn, leather, paper, metal, glass, ceramics etc. About one-third of the plastics produced are used for packaging purposes. Other uses include piping, plumbing, automobiles, furniture, toys etc. They are also used in medical field for polymer implants.

Plastics are advantageous as they are strong, light weight, low cost and durable. The production of plastic increased from 0.5 million tonnes in 1950 to over 260 million tonnes now. However, they are disadvantageous as they are resistant to biodegradation, leading to pollution, harmful to natural environment. To prevent accumulation of plastic it should be properly disposed. Improperly disposed plastic materials are significant source of environmental pollution.

Many animals die of waste plastics either by being caught in the waste plastic traps or by swallowing the waste plastic debris to exert ruinous effects on the ecosystem. Some of the plastic products cause human health problems because they mimic human hormone. The plastic sheets or bags do not allow water and air to go into the earth which causes soil infertility. In sea,

polyethylene sometimes cause blockage in intestine of fish, birds and marine mammals. Burning plastics usually produce some toxic gases like furans and dioxins which are dangerous greenhouse gases and play an important role in ozone layer depletion.

Incineration, recycling and land filling are some of the traditional methods for handling plastic wastes. However, these methods are costly and often create new environmental difficulties. When compared to other methods, biodegradation is pollution friendly. A new type of plastic called as bioplastic is now being manufactured. Bioplastics are biodegradable in nature meaning that these are either manufactured from fossils or from biomass.

Biodegradation is the break down or degradation on exposure to biological agents like bacteria, fungi, enzymes etc. thereby reducing the molecular weight. Fully biodegradable plastics are costly but under proper conditions microorganisms can be employed effectively to degrade plastics.

Microbial degradation of plastics is caused by oxidation or hydrolysis using microbial enzymes that leads to chain cleavage of polymer into monomer. Aerobic metabolism results in Carbon dioxide and water whereas anaerobic metabolism results in carbon dioxide, water and methane as end products respectively.

II. CLASSIFICATION OF PLASTICS

Based on their, thermal properties, degradable properties, chemical composition the plastics are classified into various types.

A. Classification on the Basis Of Degradability

Plastics can be classified into non-degradable and degradable polymers (Ghosh et al., 2013).

Non-biodegradable plastics

Non-biodegradable plastics also known as synthetic plastics are derived from petrochemicals and are very high molecular weight polymers. They do not degrade naturally and hence accumulate in environment.

Biodegradable plastics

Biodegradable plastics are synthesized from natural sources such as components of algae, plants and animals which act as the source of cellulose, starch and protein for their synthesis. They get easily degraded on interaction with UV rays, water, enzymes, gradual changes in pH etc. They are further classified into four classes (Arikan et al., 2014).

Bio-based bio plastics

Plastics in which whole proportion of carbon is derived from agricultural and forestry resources such as corn starch, soybean protein etc.

Biodegradable bio plastics

These plastics get degraded completely by microorganisms into biogases and biomass (mainly carbon dioxide and water) without leaving behind any toxic byproducts (Jain et al., 2010).

Compostable bio plastics

These bio plastics get decomposed biologically on composting that occurs at a similar rate as that of other compostable materials without producing any toxic remainders.

Photodegradable bio plastics

These plastics have light sensitive groups attached into their backbone, hence, on getting exposure of UV light for a long period of time disintegrate their polymeric structure.

B. Some Common Plastics

POLYETHYLENE TEREPHTHALATE (PET OR PETE): John Rex Whinfield invented a new polymer in 1941 when he condensed ethylene glycol with terephthalic acid. The condensate was polyethylene terephthalate (PET or PETE). PET is a thermoplastic that can be drawn into fibers (like Dacron) and films (like Mylar). It's the main plastic in ziplock food storage bags.

POLYSTYRENE (STYROFOAM): Polystyrene is formed by styrene molecules. The double bond between the CH2 and CH parts of the molecule rearranges to form a bond with adjacent styrene molecules, thereby producing polystyrene. It can form a hard impact-resistant plastic for furniture, cabinets (for computer monitors and TVs), glasses and utensils. When polystyrene is heated and air blown through the mixture, it forms Styrofoam. Styrofoam is lightweight, moldable and an excellent insulator.

POLYVINYL CHLORIDE (PVC): PVC is a thermoplastic that is formed when vinyl chloride (CH2=CH-Cl) polymerizes. When made, it's brittle, so manufacturers add a plasticizer liquid to make it soft and moldable. PVC is commonly used for pipes and plumbing because it's durable, can't be corroded and is cheaper than metal pipes. Over long periods of time, however, the plasticizer may leach out of it, rendering it brittle and breakable.

POLYTETRAFLUOROETHYLENE (TEFLON): Teflon was made in 1938 by DuPont. It's created by polymerization of tetrafluoroethylene molecules (CF2=CF2). The

polymer is stable, heat-resistant, strong, resistant to many chemicals and has a nearly frictionless surface. Teflon is used in plumbing tape, cookware, tubing, waterproof coatings, films and bearings.

POLYVINYLIDINE CHLORIDE (SARAN): Dow makes Saran resins, which are synthesized by polymerization of vinylidine chloride molecules ($CH_2=CCl_2$). The polymer can be drawn into films and wraps that are impermeable to food odors. Saran wrap is a popular plastic for packaging foods.

POLYETHYLENE, LDPE AND HDPE: The most common polymer in plastics is polyethylene, which is made from ethylene monomers ($CH_2=CH_2$). The first polyethylene was made in 1934. Today, we call it low-density polyethylene (LDPE) because it will float in a mixture of alcohol and water. In LDPE, the polymer strands are entangled and loosely organized, so it's soft and flexible. It was first used to insulate electrical wires, but today it's used in films, wraps, bottles, disposable gloves and garbage bags.

HDPE is a harder plastic with a higher melting point than LDPE, and it sinks in an alcohol-water mixture. HDPE was first introduced in the hula hoop, but today it's mostly used in containers.

POLYPROPYLENE (PP): In 1953, Karl Ziegler and Giulio Natta, working independently, prepared polypropylene from propylene monomers ($CH_2=CHCH_3$) and received the Nobel Prize in Chemistry in 1963. The various forms of polypropylene have different melting points and hardnesses. Polypropylene is used in car trim, battery cases, bottles, tubes, filaments and bags.

III. BIOPLASTICS: AN ALTERNATIVE TO PLASTICS

Plastics derived from renewable sources like oils, corn starch, vegetable fat etc. are referred to as bioplastics. They can also be made up using microorganisms, agricultural by products, starch, biopolymers etc.

TYPES OF BIOPLASTICS

There are different types of bioplastics being tried to be manufactured at large scale. Some of these are mentioned below.

STARCH-BASED BIOPLASTICS:

These are the most widely used bioplastics and these can also be manufactured at home. Starch can absorb humidity which makes it suitable candidate for drug capsule production. Starch can also be processed thermo-plastically as sorbitol and glycerine can also be added to starch. Starch based bioplastics are sometimes mixed with biodegradable polyesters to produce polycaprolactone.

POLYLACTIC ACID (PLA):

Corn and dextrose are used to produce polylactic acid which is transparent in nature. It carries same characteristics as petrochemical-based plastics and can also be produced using production method followed for conventional plastics. PLA is generally used in production of films, fibers, cups, and bottles.

POLY-3-HYDROXYBUTYRATE (PHB):

Certain bacteria producing glucose and corn starch can be used for production of poly-3-hydroxybutyrate. It carries same characteristics as that of plastic polypropylene. South American sugar industry uses PHB in packing purpose. PHB can also be processed into transparent film and has melting point higher than 130°C and is biodegradable in nature.

POLYHYDROXYALKANOATES (PHA):

These are linear polymers produced by bacterial fermentation of sugars and lipids. Bacteria produce it to store carbon and energy. At industrial level, the polymer is extracted from bacteria and is used in sugar fermentation. PHA is more ductile but less elastic, PHA is also biodegradable. PHA also has its application in the medical industry.

POLYAMIDE 11 (PA 11):

It is derived from natural oils and is under trade name Rilsan B, manufactured by Arkema. PA 11 is not biodegradable and its properties are similar to PA 12. PA 11 finds its application in automatic fuel lines, pneumatic airbrake tubing, flexible oil and gas pipes. Polyamide 410 (PLA 410) is derived from castor oil under trade name EcoPaXX and is manufactured by DSM. PA 410 has high melting point of approximately 250°C, has low moisture absorption, and is highly resistant to some chemical substances.

FACTORS AFFECTING PLASTIC BIODEGRADATION

Several factors affect the biodegradation process including the polymer properties, the exposure conditions, and the enzyme characteristics. Some of these factors are listed below.

EXPOSURE CONDITIONS

MOISTURE

Moisture can influence polymer biodegradation in different ways due to the essential requirement of water for growth and multiplication of microbes. Hence, polymer degradation speed is enhanced in the presence of sufficient moisture due to swift microbial action (Ho et al. 1999).

pH AND TEMPERATURE

The pH can modify the rate of hydrolysis reactions by changing the acidic or basic conditions. For example, at pH 5, the rate of hydrolysis of PLA capsules is optimal (Auras et al. 2004; Henton et al.2005). Degradation products of various polymers alter the pH conditions followed by the rate of the degradation process and microbial growth. Similarly, enzymatic degradability is affected significantly by the polymer's softening temperature. Polyester with the higher melting point has less possibility of biodegradation. Potential enzymatic degradability decreases with the increase in temperature. For instance, purified lipase of R. delemar efficiently hydrolyzed polyesters like PCL showing low melting points (Tokiwa and Calabia 2004; Tokiwa et al. 2009).

ENZYME CHARACTERISTICS

Different enzymes possess unique active sites and have the ability to biodegrade various types of polymers. For instance, straight chain polyesters ,obtained from diacid monomers with 6 to 12 C-atoms, have been degraded quickly by enzymes produced by fungal species A.flavus and A.niger as compared to straight chain polyesters produced from any other monomer (Kaleetal.2007).It was found that the extracellular enzymes, involved in the depolymerization of PHB (depolymerases), degrade PHB by distinct mechanisms depend on the specific microbially produced depolymerase (Yamada-Onodera et al. 2001).Plastics derived from the petrochemical sources, due to their hydrophobicity and 3D structure, cannot be readily degraded in the environment (Yamada-Onodera et al. 2001). Moreover, the hydrophobic nature of PE intervenes in the formation of a biofilm of microorganisms to reduce biodegradation rate (Hadad et al. 2005).

IV. POLYMER CHARACTERISTICS

MOLECULAR WEIGHT

From the biodegradability point of view, molecular weight plays a very critical role in defining many polymer properties. Degradability is lowered with the increase in molecular weight. Higher molecular weight PCL (>4000) was slowly degraded by lipase of a strain R. delemar as compared to low molecular weight polymer (Tokiwa et al. 2009). It becomes convenient for microbial enzymes to attack a substrate low in molecular weight (Auras et al. 2004).

SHAPE AND SIZE

The properties like shape and size of the polymer play an important role in the degradation process. The polymers having large surface area can be degraded quickly as compared to those with a small surface area (Kijchavengkul and Auras 2008; Stevens 2003).

ADDITIVES

Non-polymeric contaminants such as dyes (waste or debris of catalysts used for the polymerization and additives conversion products) or filler affect the degradation ability. It has been said that when the lingo-cellulosic filler increases in the sample,the thermal stability is reduced followed by increase in the ash content. The dispersal and interfacial adhesion between the lingo-cellulosic filler and the thermoplastic polymer are the major factors influencing the thermal stability of the composite system (Yang et al. 2005). Similarly, metals serve as good pro-oxidants in polyolefin manufacturing of polymers sensitive to thermo-oxidative degradation.

BIOSURFACTANTS

Biosurfactants are amphiphilic compounds produced mostly on the living surfaces. Biodegradation of polymers (fossil based and bio-based) is enhanced by the addition of a biosurfactant due to their low toxicity and high biodegradability (Orr et al. 2004). Biosurfactants facilitate the biodegradation process due to the presence of specific functional groups, and thus, they allow the activity under extreme temperature, pH, and salinity conditions (Kawai et al. 2002; Kawai et al. 2004).

THE ROLE OF MICROBES IN BIODEGRADATION

Microorganisms are ideally suited for the degradation of plastics because they possess enzymes that allow them to use environmental contaminants as food and because they are so small that they are able to contact contaminants easily. The bioremediation systems in operation today depend on microorganisms native to the contaminated sites, encouraging them to work by supplying them with the optimum levels of nutrients and other chemicals essential for their metabolism. Researchers are currently investigating ways to augment contaminated sites with the genetically engineered microorganisms especially suitable for degrading the contaminants of that particular site (Kerr, 1994). Microbial transformation of organic contaminants normally occurs because the organisms can use the contaminants for their own growth and reproduction. Organic contaminants serve two purposes for the organisms: they provide a source

of carbon, which is one of the basic building blocks of new cell constituents, and they provide electrons, which the organisms can extract to obtain energy (Chapelle, 1993). Microorganisms gain energy by catalyzing energy-producing chemical reactions that involve breaking chemical bonds and transferring electrons away from the contaminant. This type of chemical reaction is called an oxidation–reduction reaction: the organic contaminant is oxidized, the chemical that gains the electrons is reduced. The contaminant is called the electron donor, while the electron recipient is called the electron acceptor (National Research Council, 1993). The energy gained from these electron transfers is then "invested," along with some electrons and carbon from the contaminant, to produce more cells.

The process of destroying organic compounds with the aid of O2 is called aerobic respiration. In aerobic respiration, microbes use O2 to oxidize part of the carbon in the contaminant to carbon dioxide (CO2), with the rest of the carbon used to produce new cell mass. In the process the O2 gets reduced, producing water. Thus, the major by-products of aerobic respiration are carbon dioxide, water, and an increased population of microorganisms (USEPA, 1987). Many microorganisms can exist without oxygen, using a process called anaerobic respiration. In anaerobic respiration, nitrate (NO3−), sulfate (SO42−), metals such as iron (Fe3+) and manganese (Mn4+), or even CO2 can play the role of oxygen, accepting electrons from the degraded contaminant (National Research Council, 1993). Thus, anaerobic respiration uses inorganic chemicals as electron acceptors. In addition to new cell matter, the by-products of anaerobic respiration may include nitrogen gas (N2), hydrogen sulfide (H2S), reduced forms of metals, and methane (CH4), depending on the electron acceptor.

Oxidative degradation is the main mechanism for the degradation of plastics. These mechanisms reduce the molecular weight of the material. The extracellular and intracellular enzymes that are produced by the microbes convert the polymer into monomer, dimer, and oligomer. The by-products produced during conversion enters into the microbial cell can be utilized as the energy source (Shimao, 2001). A bacterium could constantly synthesis all of the enzymes required for degradation or else could activate enzyme synthesis as necessary to metabolize when needed or is thermodynamically favourable (Albertsson et al., 1987). Balasubramanian et al. (2014) reported that the environmental factors (physical and chemical) play a major role to initiate the HDPE degradation and also support the microorganisms to degrade PE (HDPE).

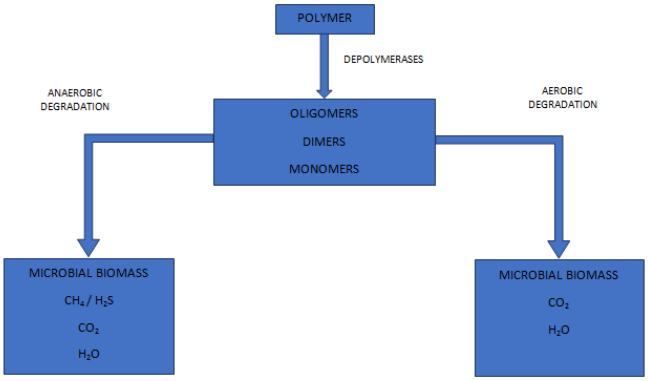

Fig: Polymer degradation under aerobic & anaerobic condition

THE ROLE OF ENZYMES IN BIODEGRADATION

The use of microbes for bioremediation has many limitations. Costly and time-consuming methods may be necessary to produce microbial cultures. Several factors include physical and chemical treatments, toxins, action of predators and high concentration of pollutants may damage or metabolically inactive the microbial cells. Enzymes exist in every living cell and hence in all microbes. Relative amounts of the various enzymes produced by the microorganisms vary with species and even between strains of the same species. Enzymes are very specific in their action on substrates, so the different enzymes help in the degradation of various types of enzymes (Underkofler, 1958).

Laccase can help in the oxidation of the hydrocarbon backbone of PE. Gel permeation chromatography (GPC) determine whether cell-free laccase incubated with PE helps in the reduction of average molecular weight and average molecular number of PE by 20% and 15%, respectively (Sivan, 2011). Laccases are mostly present in lignin biodegrading fungi, where they catalyze the oxidation of aromatic compounds. Laccase activity is known to act on nonaromatic substrates (Mayer and Staples, 2002). Lignin and manganese-dependent peroxidases (LiP and MnP, respectively) and laccases are the three main enzymes of ligninolytic system (Hofrichter et al., 2001). Some strains that are capable of degrading the PE are Brevibacillus spp., Bacillus spp., where proteases are responsible for degradation (Sivan, 2011).

Papain and urease are the two proteolytic enzymes found to degrade medical polyester PU. Polymer degraded by papain was due to the hydrolysis of urethane and urea linkages producing free amine and hydroxyl groups (Phua et al., 1987). Lignin-degrading fungi and manganese peroxidase, partially purified from the strain of Phanerochaete chrysosporium also helps in the degradation of high-molecular weight PE under nitrogen and carbon limited conditions (Shimao, 2001). The enzymes responsible for the degradation of various types of plastics depict the substrates that utilize the plastics as carbon and energy sources and helps in biodegradation. Microbial enzymes induce the rate of biodegradation of plastics very effectively without causing any harm to the environment.

V. MECHANISM OF PLASTIC DEGRADATION BY MICROORGANISMS

Bacteria and fungi both are involved in the degradation of natural as well as synthetic plastics (Gu et al., 2000a). Biodegradation of plastics or any other complex material proceeds variably under different environmental conditions in accordance with their properties as different microorganisms have different optimum growth conditions (Glass and Swift, 1989). When there is abundant oxygen, aerobic microorganisms are responsible for the conversion of complex compounds into simpler ones yielding microbial biomass, carbon dioxide and water as the final products. Extracellular and intracellular depolymerase enzymes are the two main categories which are involved actively in natural degradation of polymers (Doi, 1990; Gu et al., 2000b). Exoenzymes process by converting complex compounds into simple molecules that are small enough to pass through the semi permeable bacterial plasma membrane and then utilized them as carbon and energy resources while endoenzymes work by hydrolyzing the different bonds that hold the polymers. Major steps involved in the biodegradation of plastics are given as under.

BIO-DETERIORATION

It is a natural process in which plastic gets modified chemically, physically and mechanically by the superficial degradation caused by microbes and decomposer organisms. Abiotic parameters are the main factors that helps in weakening the polymeric structure of the plastics (Helbling et al., 2006; Ipekoglu et al., 2007) and also behave as a synergistic factor by initiating the biodeterioration process (Jakubowicz et al., 2006). This process is triggered by the formation of biofilm over the surface of plastic. The formation of biofilm depends upon the chemical composition and physical structure of the plastic as well as on the prevailing environmental conditions (Lugauskas et al., 2003). The microbial film leads to the growth of the highly diverse microbial community on the plastic that causes its chemical and physical deterioration (Zettler et al., 2013). The development of biofilm is associated with the secretion of extracellular polymeric substances (EPS) which reinforces the cohesion of the microbial film and its adhesion over the surface of plastic. These secretory EPS enter the pores of the plastic thus increasing the pore size which in turn promotes the formation of cracks that weakens the physical structure of the plastic, hence contributing to physical deterioration (Bonhomme et al., 2003).

Biofilm formation also causes the release of acidic compounds such as nitrous acid (Nitrosomonas sp.), nitric acid (Nitrobacter sp.) or sulphuric acid (Thiobacillus sp.) by chemolithotrophic bacteria. Organic acids such as citric, fumaric, gluconic, glutaric, glyoxalic, oxalic and oxaloacetic acids are also released by chemoorganotrophic bacteria. The formation of acid leads to the change in the pH inside the pores that result in progressive degradation of plastic causing changes in their microstructure contributing to the chemical deterioration of plastic.

BIO-FRAGMENTATION

This term refers to the catalytic action of the ecto enzymes or the free radicals secreted by the microbial community that cleaves the polymeric plastics into oligomers, dimers or monomers. Due to their high molecular weight plastics could not cross the cell wall of microorganisms, hence, microbes secrete the extracellular enzymes that catalyzes the reaction mainly at the surface of the plastic. Bacteria generally require the imbalance electric potential to perform lysis and causing further chemical reactions. But the highly stabilized structure of plastics owing to the long chains of carbon and hydrogen resulted in its balanced charge. Therefore, to destabilize this local electric charge, bacteria generally secrete oxygenases that adds up oxygen to the long carbon chain of plastic. For instance, mono-oxygenases and dioxygenases incorporate one and two oxygen atoms respectively forming alcohol or peroxyl groups that are less resilient for biodegradation. Further transformations are then catalyzed by esterases and lipases after the formation of

carboxylic groups and by endopeptidases after amide group formation (Lugauskas et al., 2003).

ASSIMILATION AND MINERALIZATION

Assimilation is the integration of molecules inside the microbial cells with or without getting degraded completely. Formation of monomers does not ensure their assimilation by microbes. Some monomers remain in the surrounding environment of microbial cells without getting assimilated. Monomers require specific carriers to cross the cell wall and/or cytoplasmic membrane of microorganisms. The plastic monomers get oxidized inside the microbial cells through the catabolic pathways resulted in the production of energy and biomass. Microorganisms that do not have the pathways to catabolize the secondary metabolites produced as a result of assimilation transport them outside the cell where they further used by other cell for degradation or may stay outside the cell.

VI. METHODS OF BIODEGRADATION OF PLASTICS

Muhammad, A.I. et. al in their study carried out 3 experiments to observe the biodegradation of plastics.

SOIL BURIAL TREATMENT

In Soil burial treatment soil was taken in different pots and replicate pieces of polyethylene films were buried in the that soil in pots for three months. Ground soil was inoculated with the sewage sludge for the isolation of microbial strains having ability to adhere and degrade the polymer film.

SHAKE FLASK EXPERIMENT

Cellulose blended PVC films were incubated with the isolated microbes from soil burial experiments in shaking condition. Mineral salt media used per 1000 mL contained in distilled water were; K2HPO4, 1 g; KH2PO4, 0.2 g; NaCl, 1 g; CaCl2.2H2O 0.002 g; boric acid, 0.005 gm; (NH4)2SO4, 1 g; MgSO4.7H2O, 0.5 g; CuSO4.5H2O, 0.001 g; ZnSO4.7H2O, 0.001 g; MnSO4.H2O, 0.001 g and FeSO4.7H2O, 0.01 g. Cellulose blended PVC film (3 pieces) in MSM (90 mL) were inoculated with 10 mL of spore suspension (10 ± 2.1 × 106 spores mL -1) and incubated at 30°C for 3 months. After every 4 weeks polymer samples were retrieved and evaluated visually and with infrared spectroscopy measured on Bio- Rad Merlin FTIR.

STURM TEST

CO2 evolution as a result of cellulose blended PVC biodegradation was determined by sturm test. The pieces of polymer were added to culture bottles containing MSM (285 mL) without any carbon source. Spore suspension of Phanerochaete chyrosporium PV1 (2.9 × 106 spores mL-1) wasused as inoculum 5% (v/v) in test and control bottles (without plastic). Sterlized air was supplied to keep conditions aerobic and reaction bottles were stirred continuously by placing them on magnetic stirrer. After 30 days, gravimetric analysis of CO2 production was done by trapping the gas in adsorption bottle containing KOH (1 M). The precipitates formed after titration with barium chloride solution (1 M) of test and control were filtered, weighed and calculated for CO produced per litre.

COMPOSTING TECHNIQUE

The composting was run under controlled conditions in a thermal insulated composting chamber using a standard mixture of raw materials used for cultivation of white button mushroom (Agaricus bisporus) obtained from a local mushroom compost-producing company. Specimen of polymeric foils in small stainless-steel containers were buried in the compost pile for 42,100 or 180 days; during first weeks the temperature in the pile was close to 60°C.

TECHNIQUES USED FOR ANALYSIS OF PLASTIC BIODEGRADATION

Biodegradability of polymer can be characterized by monitoring CO2 evolution rate, O2 uptake, change in properties of polymer (chemical & physical), growth rate of organisms. Multiple tests should be followed in evaluating plastic degradation due to following reasons (Mohan and Shrivastava 2010)

- Weight loss may be due to leaching of additives, including plasticizers
- carbon dioxide production might result from the degradation of low molecular weight fraction of the polymer, with no degradation of longer chains.
- Loss of additives or very small change in chemical makeup plastic may affect strength of plastic There are several techniques available for checking the degree and nature of degradation products of microbially degraded / treated plastics.

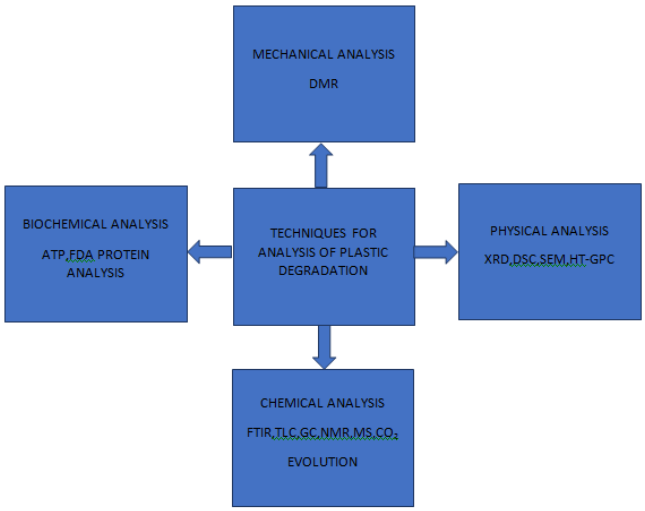

Fig: Techniques for analysis of plastic degradation

TOXICITY OF BIODEGRADED PLASTIC

Several plastic products can be toxic due to the presence of some additives in them, e. g. The compounds leaching from polystyrene food containers have been predicted to interfere with hormone functions and are supposed to have carcinogenic effect. The finished plastic is non-toxic but the monomers that are used in the production of the parent polymers can be toxic.

Toxicity study of biodegraded polythene on plants was monitored by observing their effect on seed germination in seeds like ground nut, sunflower, safflower, sesame and soybean (Aswale 2010). It was recorded that seed germination (%) decreases in treated seeds, while in case of larvae (Chironomous spp.) no toxicity was detected in terms of decreases in mortality rate. S. aureus, P. aeruginosa, A. niger, Rhizopus spp. and Streptomyces spp. were used for degradation of polythene bags and plastic cups and toxicity level of biodegraded polythene was studied using Vigna radiata. It was observed that addition of biotreated polythene granules reduced soil pores size, which may have negative effect on the nutrient uptake by the root of plant. (Kannahi and Sudha 2013).

VII. CONCLUSION

It is obvious that we cannot live without plastics to meet our daily needs, but the only solution to this problem is that we have to develop competent process for its degradation and safe disposal. To solve the problems related to the disposal of plastic waste produced from various sources, the most innovative and environmentally safe way is to use biodegradable plastics in certain applications like packaging, agriculture, and health industry.

REFERENCES

[1] Albertsson AC, Andersson SO, and Karlsson S(1987). The mechanism of biodegradation of polyethylene. Polymer Degradation and Stability 18: 73–87.
[2] Arikan EB, Ozsoy HD(2014). Time to bioplastics. Akademik Platform. Istanbul, Turkey, 743-750.
[3] Aruna Muthukumar, Shanthi Veerappapillai biodegradation of plastics; a brief review (2015). Int. J. Pharm. Sci. Rev. Res. 36: 204- 209.
[4] Aswale P (2010) Studies on bio-degradation of polythene. PhD thesis, Dr Babasaheb Ambedkar Marathwada University, Aurangabad, India.
[5] Auras R, Harte B, Selke S (2004) An overview of polylactides as packaging materials. Macromol Biosci 4(9):835–864.
[6] Bunty Sharma, Himanshi Rawat, Pooja and Ruchika Sharma (2017). Bioremediation - A Progressive Approach toward Reducing Plastic Wastes. Int.J.Curr.Microbiol.App.Sci. 6(12): 1116-1131.
[7] Chapelle F (1993). Ground-Water Microbiology & Geochemistry. John Wiley & Sons, Inc., New York.
[8] Doi Y (1990). Microbial Polyesters. VCH Publishers, New York.
[9] Esmaeili A, Pourbabaee AA, Alikhani HA, Shabani F, Esmaeili E (2013). Biodegradation of Low-Density Polyethylene (LDPE) by Mixed Culture of Lysinibacillus xylanilyticus and Aspergillus niger in Soil. PLoS ONE. 8(9): e71720.
[10] Fortman DJ; BrutmanJP; Cramer CJ; Hillmyer MA; Dichtel WR (2015). JACS. 137 (44), 14019–14022.
[11] Gautam N, Kaur I (2013). Soil burial biodegradation studies of starch grafted polyethylene and identification of Rhizobium meliloti therefrom Journal of Environmental Chemistry and Ecotoxicology;5(6):147- 58.
[12] Ghosh SK, Pal S, Ray S (2013). Study of microbes having potentiality for biodegradation of plastics. Environmental Science and Pollution Research, 20:4339-4355.
[13] Glass JE, Swift G (1989). Agricultural and Synthetic Polymers: Biodegradation and Utilization, ACS Symposium Series No. 433. American Chemical Society, Washington DC, 9–64.
[14] Gu JD, Ford TE, Mitton DB, Mitchell R (2000a). Microbial corrosion of metals. In: Revie W, editor. The Uhlig Corrosion Handbook. Wiley, New York, 2:915–27.
[15] Gu JD, Ford TE, Mitton DB, Mitchell R (2000b). Microbial degradation and deterioration of polymeric materials. In: Revie W, editor. The Uhlig Corrosion Handbook. Wiley, New York, 2:439–60.
[16] Hadad D, Geresh S, Sivan A (2005) Biodegradation of polyethylene by the thermophilic bacterium Brevibacillus borstelensis. J Appl Microbiol 98:1093–1100.
[17] Helbling C, Abanilla M, Lee L, Karbhari VM (2006). Issues of variability and durability under synergistic exposure conditions related to advanced polymer composites in civil infrastructure. Composites Part A: Applied Science and Manufacturing, 37:1102–1110.
[18] HentonDE,GruberP, LuntJ, RandallJ(2005). Polylacticacid technology natural fibers, biopolymers, and biocomposites 16:527–577.
[19] Ho K-LG, Pometto AL III, Hinz PN (1999) Effects of temperature and relative humidity on polylactic acid plastic degradation. J Environ Polym Degrad 7(2):83–92.
[20] Ipekoglu B, Böke H, Cizer O (2007). Assessment of material use in relation to climate in historical buildings. Building and Environment, 42:970-978.

[21] Jain R, Kosta S, Tiwari A (2010). Polyhydroxy alkanoates: a way to sustainable development of bioplastics. Chronicles of Young Scientists, 1:10-15.
[22] Jakubowicz I, Yarahmadi N, Petersen H (2006). Evaluation of the rate of abiotic degradation of biodegradable polyethylene in various environments. Polymer Degradation and Stability, 91:1556–1562.
[23] KaleG,KijchavengkulT,AurasR,RubinoM,SelkeSE,SinghSP(2007) Compostability of bioplastic packaging materials: an overview. Macromol Biosci 7(3):255–277.
[24] Kannahi M, Sudha P (2013) Screening of polythene and plastic degrading microbes from Muthupet mangrove soil. J Chem Pharm Res 5(8):122-127.
[25] Kathiresan K (2003) Polythene and Plastics-degrading microbes from the mangrove soil. Rev Biol Trop 51(3):629-634.
[26] Kawai F, Watanabe M, Shibata M, Yokoyama S, Sudate Y (2002) Experimental analysis and numerical simulation for biodegradability of polyethylene. Polym Degrad Stab 76(1):129–135.
[27] Kawai F, Watanabe M, Shibata M, Yokoyama S, Sudate Y, Hayashi S (2004) Comparative study on biodegradability of polyethylene wax by bacteria and fungi. Polym Degrad Stab 86(1):105–114.
[28] Kerr RS (1994). Handbook of Bioremediation. CRC Press, Inc. Lewis Publishers, Boca Raton, FL, pp. 85–96.
[29] KijchavengkulT, AurasR(2008). Compostability of polymers. PolymInt 57(6):793–804.
[30] Mahalakshmi V, Siddiq A, Andrew S N (2012) Analysis of Polyethylene Degrading Potentials of Microorganisms Isolated from Compost Soil. Int J Pharm Biol Sci Arch 3(5):1190-1196.
[31] Make Potato Plastic! Retrieved on 2016-01-14 from www.instructables.com
[32] Mirel: PHAs grades for Rigid Sheet and Thermoforming. Retrieved on 2016-01-14 from https://bioplastique.wordpress.com
[33] Mohan K S, Srivastava T (2010) Microbial deterioration and degradation of polymeric materials. J Biochem Tech 2(4):210-215.
[34] Muhammad AI, Perveen Q, Ahmad B, Javed I, Razi-UlHussnain R, Andleeb S, et al. (2009). Studies on Biodegradation of Cellulose Blended Polyvinyl Chloride Films. International Journal Of Agriculture and Biology.(09):175.
[35] Orr IG, Hadar Y, Sivan A (2004) Colonization, biofilm formation and biodegradation of polyethylene by a strain of Rhodococcus ruber. Appl Microbiol Biotechnol 65(1):97–104.
[36] Phua SK, Castillo E, Anderson JM, and Hiltner A (1987). Biodegradation of polyurethane in vitro. Journal of Biomedical Materials Research 21: 231–246.
[37] Priya Trivedi, Adria Hasan, Salman Akhtar, Haris Siddiqui M, Usman Sayeed Kalim M and Khan A (2016). Role of microbes in degradation of synthetic plastics and manufacture of bioplastics J. Chem. Pharm. Res., 8(3):211-216.
[38] Raziyafathima M, Praseetha P K, Rimal Isaac R S (2016). Microbial Degradation of Plastic Waste: A Review. J Pharm Chem Biol Sci, 4(2):231-242.
[39] Retrieved on 2016-01-14 from www.dsm.com.
[40] Sahni Kumar, Teotia1, Yogendra Singh (2017).A comprehensive review on microbial degradation of plastic waste. Journal of Applied Pharmaceutical Research 5(4); 08 – 12.
[41] Scott G (1999). Polymers in modern life. Polymers and the Environment. The Royal Society of Chemistry, Cambridge, UK.
[42] Sherman LM (2008). Plastics Technology, 7.
[43] Shimao M (2001). Biodegradation of plastics. Current Opinion in Biotechnology 12: 242.
[44] Sivan A (2011). New perspectives in plastic biodegradation. Current Opinion in Biotechnology 22: 422–426.
[45] Swapnil K. Kale, Amit G. Deshmukh, Mahendra S. Dudhare, Vikram B. Patil (2015). Microbial degradation of plastic: a review. J Biochem Tech 6(2): 952-961.
[46] Temoor Ahmed, Muhammad Shahid, Farrukh Azeem, Ijaz Rasul, Asad Ali Shah, Muhammad Noman, Amir Hameed, Natasha Manzoor, Irfan Manzoor & Sher Muhammad (2018).Biodegradation of plastics: current scenario and future prospects for environmental safety. Environmental Science and Pollution Research. https://doi.org/10.1007/s11356-018-1234-9.
[47] Tokiwa Y, Calabia BP (2004) Review degradation of microbial polyesters. Biotechnol Lett 26(15):1181 –1189.
[48] Tokiwa Y, Calabia BP, Ugwu CU, Aiba S (2009) Biodegradability of plastics. Int J Mol Sci 10(9):3722–3742.
[49] Underkofler LA (1958). Production of microbial enzymes and their applications. Applied Microbiology 6: 212–221.
[50] Witt U, Müller R-J, Deckwer W-D (1997). Biodegradation behavior and material properties of aliphatic/aromatic polyesters of commercial importance. Journal of environmental polymer degradation.5(2):81-9.
[51] Yang H-S, Wolcott M, Kim H-S, Kim H-J (2005). Thermal properties of lignocellulosic filler-thermoplastic polymer bio-composites. J Therm Anal Calorim 82(1):157–160.
[52] Yates RM, Barlow CY (2013). Resources, Conservation and Recycling.78, 54- 66.
[53] Zettler ER, Mincer TJ, Amaral-Zettler LA (2013). Life in the "plastisphere": microbial communities on plastic marine debris. Environmental Science and Technology, 47:7137-7146.